

BOOKSHELF

The Millennium Problems by Keith Devlin, Granta Books. Hardback ISBN 1862076863, £20.00 (\$29.95).

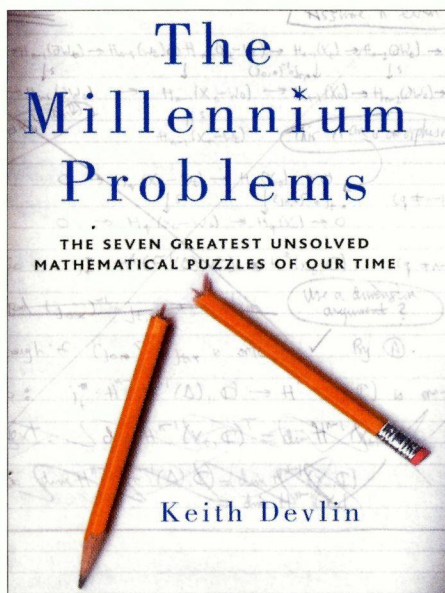
On 24 May 2000 in a lecture hall at the Collège de France in Paris, Michael Atiyah from the UK and John Tate from the US announced that a \$1 million prize would be granted to those who first solved one of the seven most difficult open problems in mathematics. These are known as the “Millennium Problems”, and the whole idea was an initiative of the Clay Mathematical Institute (CMI), which was established one year earlier by magnate Landon Clay. The list of problems was selected by a committee of top mathematicians, including – along with Atiyah and Tate – Arthur Jaffe, the current director of the CMI, Alain Connes, Andrew Wiles and Edward Witten, the only physicist, who is also a Fields medallist.

One-hundred years before, also in Paris, David Hilbert had given the famous address laying out an agenda for the mathematics of the 20th century. He proposed a total of 23 problems; a few turned out to be simpler than anticipated, or were too imprecise to admit a definite answer, but most were genuine, difficult and important problems that brought instant fame and glory (if not necessarily wealth) to those who solved them.

Some of the differences between the two sets of problems should be mentioned. While Hilbert’s set provided a guideline for mathematics research, the Millennium Problems provide a description of the current frontier of knowledge in the subject. The other important difference is that among the CMI set, two are inspired by deep physics problems: fluid dynamics and the structure of gauge theories.

In this book, Keith Devlin, a well known mathematician who writes excellent books and articles for a lay audience, takes up the daunting task of explaining these problems as best as can be done to an audience assumed to have no mathematical sophistication beyond the high-school curriculum – and all this in only about 200 pages! Although such an ambitious aim is nigh on surreal, the results are quite satisfactory. The book is able to communicate to a large extent the depth and importance of the problems, and to give a glimpse of the deep elation whoever solves them will feel. For anyone involved in research, the \$1 million prize is almost beside the point.

The author chooses to present the problems from the “simplest” to the most arcane. The first is the Riemann hypothesis. Deeply related



to the distribution of prime numbers, this is the only one of the problems proposed by Hilbert that has not been settled. Technically, one needs to find the location of the zeros of a certain function (Riemann’s zeta function). If proven true, there are literally hundreds of important results in number theory that would follow, and it is quite likely that a poll among mathematicians would identify this as the most important open problem in mathematics.

The second problem has a physics flavour to it. All the basic interactions in the Standard Model of particle physics are gauge interactions. If we consider the idealized situation of a pure gauge theory, we would like to have a mathematically sound proof that the quantum theory exhibits confinement, and that the mass of the first excited state is definitely positive (there is a mass gap). Most physicists would agree with these properties, however, a real proof may provide completely new methods in quantum field theory that may bring a revolution similar to the invention of calculus by Leibnitz and Newton.

The third problem is related to computational complexity where one can ask, among those functions or propositions that can be computed, which are “easy” and which are “hard”. Problems that can be solved in polynomial time with respect to the length of the input (in bits) are assigned to complexity class P, while the class NP contains problems that are considered hard because, so far, any algorithm used to solve them requires exponential time. Among the latter, one of the most famous is the travelling-salesman

problem. Nobody knows whether the classes P and NP are equivalent. This is a central problem in computational theory and its resolution may have far-reaching technological consequences.

The fourth problem again has a physics flavour, and is related to the Navier–Stokes equation describing the fluid flow of an incompressible fluid with viscosity. It is difficult to exaggerate the importance of this equation in the design of aeroplanes and ships. Although there are plenty of approximation and numerical methods, as in the case of gauge theories, we are still lacking a deep mathematical methodology that will allow us to understand in detail the space of solutions for given initial data. To appreciate the difficulty of the problem, a solution would imply a detailed understanding of the phenomenon of turbulence – no small accomplishment.

The fifth problem is at the root of modern topology: the Poincaré conjecture. Roughly speaking, topology is the study of spaces that are stable under arbitrary continuous deformations. Thus a tetrahedron or cube can be continuously deformed to a sphere, while it is impossible to do the same with the surface of a doughnut. It is a very interesting and legitimate question to ask for the complete set of topological invariants in a given dimension. In the case of a two-dimensional sphere it is clear that we cannot lasso it. This property is known as simple-connectedness and it characterizes the sphere topologically. Poincaré asked whether a similar property would completely characterize a three-dimensional sphere. During the 20th century we have achieved a topological classification for spaces whose dimension is different from three, curiously the dimension where Poincaré’s conjecture was formulated. Progress in the past two decades seems to indicate that it may be settled in the positive in a few years time.

The last two problems are truly arcane. They go under the names of the Birch and Swinnerton-Dyer, and the Hodge conjectures. To exhibit the difficulty in explaining the first, it should be noted that definite support for it came from the settling of Fermat’s last theorem by Wiles and the subsequent progress in the so-called Taniyama–Shimura conjectures. The problem is deeply rooted in the study of rational solutions to special types of equations (elliptic curves), which in turn are contained in the apparently unfathomable

world of Diophantine equations. The Hodge conjecture is, according to Devlin, the one most difficult to formulate for a lay audience. Its resolution would provide deep insights into analysis, topology and geometry, but its mere formulation requires advanced knowledge in all three subjects.

Devlin comes out with flying colours in his effort to make these fascinating problems accessible to a wide audience. It is inevitable that there are some dark corners and a few inaccuracies in such a challenging task. However, for anyone interested in the frontiers of mathematics and scientific knowledge, this book provides enthralling reading.

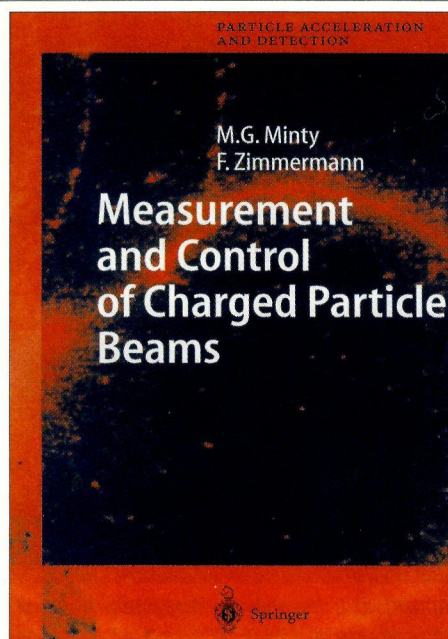
Luis Alvarez-Gaume, CERN.

Measurement and Control of Charged Particle Beams by M G Minty and F Zimmermann, Springer. Hardback ISBN 3540441875, €74.85 (£54.00, \$79.95).

This is a specialist book written primarily for the high-energy particle-accelerator community, in which Minty and Zimmermann present a contemporary view of charged-particle beam measurement and control in high-energy physics (HEP) machines. With an eye on the next generation of such machines, the authors cover, in some detail, the pioneering work being carried out around the world on electron-positron linear colliders.

The subject matter and references are laudably taken from worldwide resources. The references are given in abundance and the authors have provided an admirable service by trawling through the ever-more voluminous proceedings of conferences and schools to list the key papers. There are 172 figures, which are frequently of “live” examples taken from the world’s foremost HEP laboratories, and the authors have also taken care to expand the theory in the more advanced or less well known areas. Each chapter is backed up by exercises with solutions that provide the authors with a useful vehicle for more theoretical explanations and alternative views that could not be conveniently integrated into the text. Newcomers to HEP machines, however, should heed the warning on page 5 that the reader is expected to know basic optics and, one might add, advanced applied mathematics as well.

The experienced reader can omit the introductory chapter 1, while newcomers would be better served by building their knowledge through the more basic references given by the



authors. Thereafter, the book reads smoothly, starting with single-particle optics and moving progressively through emittance, photo-injectors, collimation, longitudinal optics, longitudinal manipulation, injection and extraction, polarization and cooling. In general, the authors start by reviewing how to measure the parameters in a particular category and then continue with how to control those parameters.

Chapter 2 starts with the measurement of transverse optical parameters. Many of the techniques described are relatively recent and depend on the tremendous advances that have been made in digital electronics and online computing power. The use of “multiknobs” is described. This concept has existed for many decades in the form of tune and chromaticity control using two independent corrector families, but it can be greatly extended using matrix techniques for quasi-linear systems and powerful matching routines for the more non-linear cases.

Chapter 3 addresses the important subject of closed-orbit correction, where the reader will be brought up to date with jargon such as “corrector ironing” (page 87). This chapter also includes newer topics such as wake-field bumps, dispersion-free steering, orbit feedback and dynamic orbits excited by an alternating-current dipole. Chapter 4 deals with the difficult task of emittance measurement and tackles both the transverse and longitudinal planes, bringing in equilibrium emittances and the control of partition

damping numbers. The next chapter briefly breaks the mould of the earlier ones by reviewing low-emittance photoinjectors and the production of flat beams using a solenoid, which together are of great importance to linear colliders.

Chapter 6 takes up collimation, but with only seven pages the reader sees relatively little of this critical subject. Collimation is important in low-energy high-intensity machines, high-energy superconducting machines and in electron-positron linear colliders. In each of these cases the problems and parameters are different. The collimation proposals for linear colliders would have fitted well into the context of this book, as the authors are clearly preparing for the next generation, while high-efficiency collimation for machines like the LHC is arguably an even more important topic that could have been included.

The book then returns to the basic mould with excellent accounts of the measurement of longitudinal optics parameters in chapter 7, followed logically by the manipulation of the longitudinal phase space in chapter 8. One small disappointment is that the tomographic measurement of longitudinal phase space, although mentioned in one of the examples and referenced, is not treated in a separate section as a diagnostic tool in its own right.

Chapter 9 could be arguably more suited to a book on lattice design and contains somewhat surprising excursions into septum and kicker magnet design. However, the reader will no doubt find extraction by resonance islands and bent crystals highly interesting. Chapter 10 on polarization fills a gap in the literature and the authors have accordingly paid more attention to theory. The practicalities of the harmonic correction of depolarizing resonances, adiabatic spin flipping, tune jumps and Siberian snakes of complete and partial types are all addressed. The final chapter describes the fascinating topics of stochastic cooling, electron cooling, laser cooling, ionization cooling, crystal beams and beam echoes, many of which merit their own monograph.

In summary, this book is a very welcome and valuable addition to the accelerator literature. As noted by the authors, there is relatively little material in the book specifically for low-energy machines, but industrial users may still find it useful to read the book and adapt or develop the ideas rather than apply them directly.

Philip Bryant, CERN.

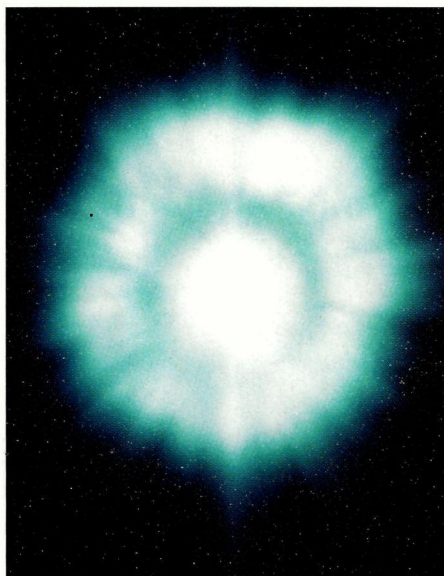
Supernovae and Gamma Ray Bursters by Kurt Weiler (ed), Springer. Hardback ISBN 3540440534, €89.95 (£69.00, \$115.80).

The association of gamma-ray bursts (GRBs) with supernova (SN) explosions has been suspected since the discovery of GRBs by the Vela satellites in 1967. However, observational evidence for a GRB–SN association was first found accidentally after the discovery of GRB afterglows 30 years later. The prompt search for an optical afterglow of GRB980425 led to the discovery, two days after the burst, of a relatively nearby supernova, SN1998bw, whose sky position and estimated explosion time were consistent with those of GRB980425. The physical association between them suggested that GRB980425 was produced by a highly relativistic and narrowly collimated jet viewed off axis and ejected by SN1998bw, which appeared to be unusually energetic for a supernova because it was viewed near axis.

These conclusions were not immediately reached by the majority of the GRB and SN communities, who were more accustomed to spherical models of SN explosions and GRB “fireballs”. So the above evidence for a GRB–SN association was at first dismissed as being either an accidental sky coincidence between a distant GRB and a close SN, or as a physical association between a new type of faint GRB (see p293 in the book) and a new type of SN, much more energetic than ordinary supernovae (SNe) and dubbed “hypernovae” (see pp243–281).

These interpretations began to erode, however, as observational data on optical afterglows of other GRBs accumulated. The data indicated that GRBs take place in star formation regions in host galaxies and their afterglows. In particular those of the relatively close GRBs show evidence that long duration GRBs are produced by jetted ejecta in SN explosions akin to SN1998bw, and not in fireballs produced by the merger of neutron stars in binary systems due to gravitational wave emission. But it was the dramatic spectroscopic discovery on 8 April 2003 of SN2003dh in the late afterglow of GRB030329 (see *CERN Courier* June 2003 p5, p13; September 2003 p15) that convinced the majority of the GRB and SN communities that ordinary, long duration GRBs are produced in SN explosions akin to SN1998bw.

The book *Supernovae and Gamma Ray*



An artist's impression of a gamma-ray burst. (Illustration by ESA/ECF.)

Bursters edited by Kurt Weiler, an expert on radio SNe, appeared shortly before the discovery of GRB030329 and SN2003dh. It contains a collection of contributions on SNe and GRBs. Many of the contributions are very informative, well written and satisfy the stated aim of *Springer's Lecture Notes In Physics*: “intended for broader readership, especially graduate students and non-specialist researchers wishing to familiarize themselves with the topic concerned.”

The first half of the book is devoted to SNe and includes contributions such as “Supernova Rates” by Enrico Capelaro and “Measuring Cosmology with Supernovae” by Saul Perlmutter and Brian Schmidt. The second half is devoted to GRBs and includes contributions such as “Observational Properties of Cosmic GRBs” by Kevin Hurley, “X-ray Observations of GRB Afterglows” by Filippo Frontera and “Optical Observations of GRB Afterglows” by Elena Pian.

However, the book as a whole is unbalanced, both in its coverage of SNe and GRBs and in its coverage of the possible GRB–SN association, which presumably was its main aim. The first half covers in great detail (seven out of ten chapters) the fireworks from the interaction of the SN ejecta with the SN environment, but lacks a detailed discussion of our current knowledge of the different SN progenitors, the mechanisms that explode them and the compact remnants that are left over. It is needless to emphasize the

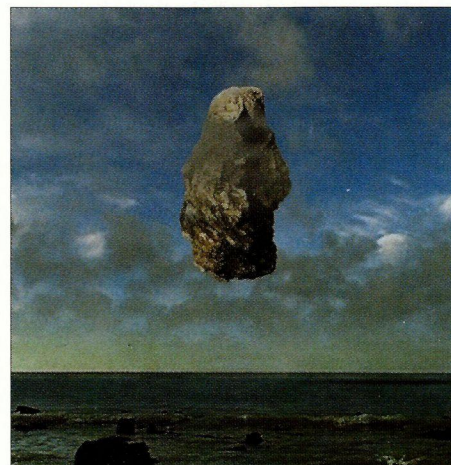
importance and relevance of these subjects to the GRB–SN association. The second part of the book, which is devoted to GRBs and their afterglows, focuses mainly (four chapters extending over 100 pages) on the observations of GRB afterglows, with only a single chapter (16 pages long) on the prompt gamma-ray emission. Our current “theoretical understanding” of GRBs is summarized in a single chapter, which is exclusively devoted to the presentation of the party line – the fireball model – as if it were a dogma. It does not discuss the model's severe problems, nor possible future tests of the model. It does not even mention alternative models, such as the “Cannonball Model”, which is *ab initio* based on a GRB–SN association, is falsifiable, and is much more predictive and successful than the fireball models.

In summary, the book contains some useful summaries of observational data on SNe and GRBs, but sheds no light on the production mechanism of SNe and GRBs, nor on the GRB–SN association.

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Chercheurs entre rêve et réalité

(Scientists at the rim of reality) a film by Samy Brunett (in French or English versions), Blue in Green Productions. DVD or VHS PAL €20.00. (Available directly from samy.brunett@village.uu.net.be.)



Bringing the fundamental physics research of today, or of the last 30–40 years, within the reach of the general public is a very difficult task. It is verging on the impossible, to be perfectly honest, as it requires some prior general scientific knowledge on the

part of the public and a great command of the subject on the part of the author(s). Having said that, the difficulty of the task does not imply that it should not be attempted, in fact quite the reverse. And this is what Samy Brunett does in his DVD on the theory of everything.

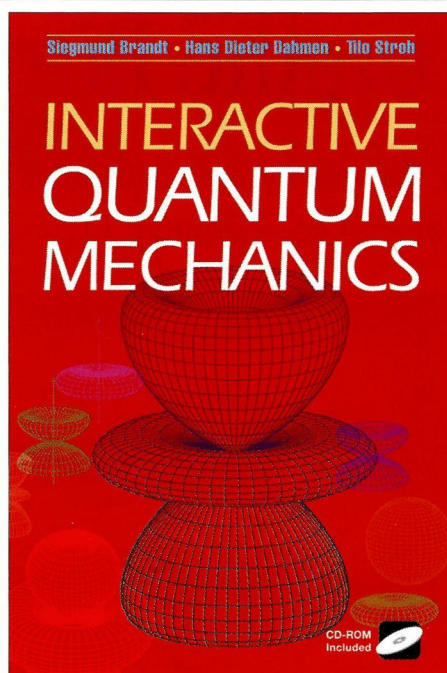
The approach chosen for Brunett's DVD is to use interviews and discussions with a number of young and not-so-young physicists who are working for or at CERN, some of whom are well known and some of whom are not (in any case, the general public is unlikely to tell the difference). These physicists are fairly representative of their profession, which is already a point in the DVD's favour, as they all speak with enthusiasm and passion.

The interviews are preceded by a number of computer-generated images, not all of which are entirely appropriate to the subject matter, which is, quite simply, the origins of the universe – a different kettle of fish altogether to the famous magic potion of Asterix the Gaul! However, having said this, once the introduction is over we do go on to meet the actual people working in physics. Those of us who will recognize it may lament the rather drab setting of the CERN cafeteria, but the sentiments are well expressed and quite convincing, whether they are uttered by young physicists or by the leading lights of the field.

Of course from a single viewing of this DVD alone, the "man in the street" is not going to aspire to understand what "we" mean today by the theory of everything, extra dimensions, the very early universe or particle mass, especially since the links between the different subjects are not always clear. However, its great merit – and certainly not the only one – is that it has been made and that it allows the viewer to get an idea of today's leading figures in fundamental research.

In the current wave of commemorative events (the recent centenaries of the discovery of radioactivity and of Einstein's first articles, for example, or CERN's 50th anniversary this year), this kind of modern technology-based publication can do nothing but good for the rather stale image of this discipline of ours that is so difficult to popularize.

Alain Méric de Bellefon, PCC-Collège de France.



Interactive Quantum Mechanics by Siegmund Brandt, Hans Dieter Dahmen and Tilo Stroth, Springer-Verlag. Hardback ISBN 387002316, €69.95 (£54.00, \$69.95).

"Physical intuition" is a precious commodity for all physicists. Richard Feynman, when asked once what his intuition was concerning a certain problem, is said to have replied that he didn't have any because he hadn't done the calculation yet. Common sense is frequently a poor guide, even in the classical domain, but there our intuition can be built up with the help of reasoned interpretations of phenomena we can experience directly, and by the performance of many relatively simple and realistic calculations. Gaining intuition about the quantum world is much harder: we have little, if any, direct perception of it, and few realistic problems are mathematically easy to solve. Thus, students have a hard time "thinking physically" when faced with quantum problems.

Surely computers ought to be able to help. Quite complicated problems can be quickly solved numerically, and – most importantly – the results can be presented in a variety of graphical forms. Indeed, several recent undergraduate texts on quantum mechanics have included disks demonstrating the solutions of standard problems. These generally have a modest capability for the student to "play with the parameters", but there has been nothing

more radically interactive. This book is the first (so far as I know) to fill this gap.

In fact, it might be more accurate to describe it as a computer program on a CD, accompanied by extended notes, rather than as a book accompanied by a CD. The program, called "INTERQUANTA" or IQ for short, has a self-explanatory user interface written in Java. It is easy to install and simple to work with – the instructions are even suitable for computer illiterates like myself. It can be used passively, to watch (and listen to) demonstrations that illustrate the main points in the text, but in the second, interactive mode the user is offered considerable freedom in designing the problems to be solved and the ways in which the answers may be displayed. As the authors put it, users can enter a "computer laboratory in quantum mechanics".

Eight physics topics are treated in as many chapters: free-particle motion, bound states and scattering, first in one and then in three dimensions; two-particle systems in one dimension; and special functions of mathematical physics. Each chapter begins with a section called "Physical Concepts", in which the relevant concepts and formulae are assembled without proof. Each section of the text is carefully keyed to a corresponding part of IQ, and the graphical outputs are well designed and easy to read. More than 300 numerical exercises are included to stimulate the reader's exploration, and many contain useful prompts encouraging the reader to suggest a physical explanation for particular results. A final chapter contains hints for the solution of some exercises, and an appendix provides a systematic guide to IQ.

IQ contains much useful material, and the authors are to be congratulated on having produced something rather novel that is so user friendly. But I believe its value would be greatly enhanced if the range of topics were to be significantly extended. For example, all the presentations are static, yet there are many fascinating and important time-dependent phenomena in quantum theory for which a "movie" would be a valuable aid to understanding. And it is a pity that the whole vital area of perturbation theory is omitted, where there is ample scope for numerical instruction. A program that included topics such as these would surely be a major resource for both students and teachers.

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